Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management

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What is stationarity?

- The assumption behind traditional hydrologic frequency analysis is that climate is stationary.
- Stationarity means that the statistical properties of hydrologic variables in future time periods will be similar to past time periods.

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“Stationarity is Dead”

- “Stationarity is a foundational concept that permeates training and practice in water-resource engineering.”
- “Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.”

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CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

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Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2*, *3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

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An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth’s climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4*, *5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*, *18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4*, *20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21*, *22*), the assumption of stationarity was

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Alternatives to Stationarity Assumption

- Although there have been academic articles criticizing the assumption of stationarity, it is not apparent what, if any, alternative methods should be used as a replacement.

Workshop Objectives

- Discuss whether there is a need for new ways to model nonstationary processes for hydrologic frequency analysis and if current approaches are not working.
- Present a range of potential alternatives for dealing with non-stationarity in hydrology both in the near term, as well as for the next generation of analytical tools that could be developed.

Workshop Objectives (continued)

- Compile workshop proceedings based on invited papers and minutes from the meeting.
- Initiate mechanisms for a continuing dialog between water managers and scientists on methods to deal with climate uncertainty.
- Formulate an ‘Action Plan’ for next steps to develop practical guidance for water managers to deal with climate uncertainty.

Organizing Agencies

- International Center for Integrated Water Resources Management
- U.S. Army Corps of Engineers
- U.S. Geological Survey
- U.S. Bureau of Reclamation
- National Oceanic and Atmospheric Administration
- Environmental Protection Agency
- Colorado State University

Some Other Agency Attendees

- Federal Emergency Management Agency
- Federal Highway Administration
- Natural Resources Conservation Service
- U.S. Forest Service
- U.S. Navy
- Denver Water

- Western Governors Association
- Manitoba Hydro

International Participants

- United Kingdom, Walker Institute, University of Reading
- Poland, Research Centre for Agricultural and Forest Environment, Polish Academy of Sciences
- Japan, International Center for Water Hazards and Risk Management
- United Kingdom, University of Exeter, London School of Economics
- Canada, Institut national de la recherche scientifique (INRS)
- Greece, National Technical University of Athens

Some Ideas from Workshop – Stationarity

- Nonstationarity is here and always was – Get over it!
- Stationarity was never alive.
- The problem is our perception that climate should be stable.

Some Ideas from Workshop – Statistical Methods

- Federal government should provide adequate resources to keep hydrologic data, information, and methods up-to-date – precipitation frequency estimates, probable maximum precipitation, methods for flood frequency estimation (Bulletin 17B).
- It may be time to give Bulletin 17B a decent burial and move on.

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Some Ideas from Workshop – Global Climate Models

- Models have deficiencies – they don't contain some physical processes and other processes are poorly represented.
- Downscaling helps people do the wrong things more precisely.
- We are riding a bicycle backwards if we look only at the historical record.
- GCM based projections give us some insights, warts and all.

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Some Ideas from Workshop – Uncertainty

- There are inherent irreducible uncertainties in climate science.
- It is a misleading idea to constrain the uncertainty in climate models.
- When using uncertain information, we must manage the residual risk.

Some Ideas from Workshop – Water Management

- Climate change challenges analytical techniques and decision making.
- We are interested in making better decisions, not in better predictions.
- We need to shift from a static design paradigm to dynamic management.
- We may need a new Harvard Water Program (an effort to improve decision making with uncertainty).

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Some Ideas from Workshop – Science

- Hydrologic community needs to better use non-traditional data.
- Scientific community needs to better understand ongoing hydrologic change.
- We need a better understanding of the mechanism of extreme events.

International Next Steps

- U.N. Secretary General's Advisory Board on Water and Sanitation (UNSGAB)/ High-Level Expert Panel on Water and Disaster (HLEP)
- LTG Robert Van Antwerp (Commanding General, U.S. Army Corps of Engineers) is member of HLEP
- Published *Water and Disaster*, a report of action plans to reduce impact of water-related disasters.

International Next Steps

- USACE has agreed to lead Task 29 action:

  "National and international hydrological institutes must take the initiative to identify underlying analytical and data requirements to meet climate changes that are likely to be highly uncertain and so as to support structural and non-structural measures for disaster risk deduction."

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Next Steps

- Proceedings including abstracts, presentations, papers – it will be an online resource for issues of nonstationarity and water management.
- Feature Collection of invited papers in *Journal of American Water Resources Association (JAWRA).*

Next Steps

- Federal agencies “must take the initiative to identify underlying analytical and data requirements to meet climate changes that are likely to be highly uncertain.”
- Federal agencies should review decision making methods for uncertain, dynamic conditions.
- What is proper working group to develop practical guidance for water managers to deal with climate uncertainty?

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Questions?

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